

Figure 1

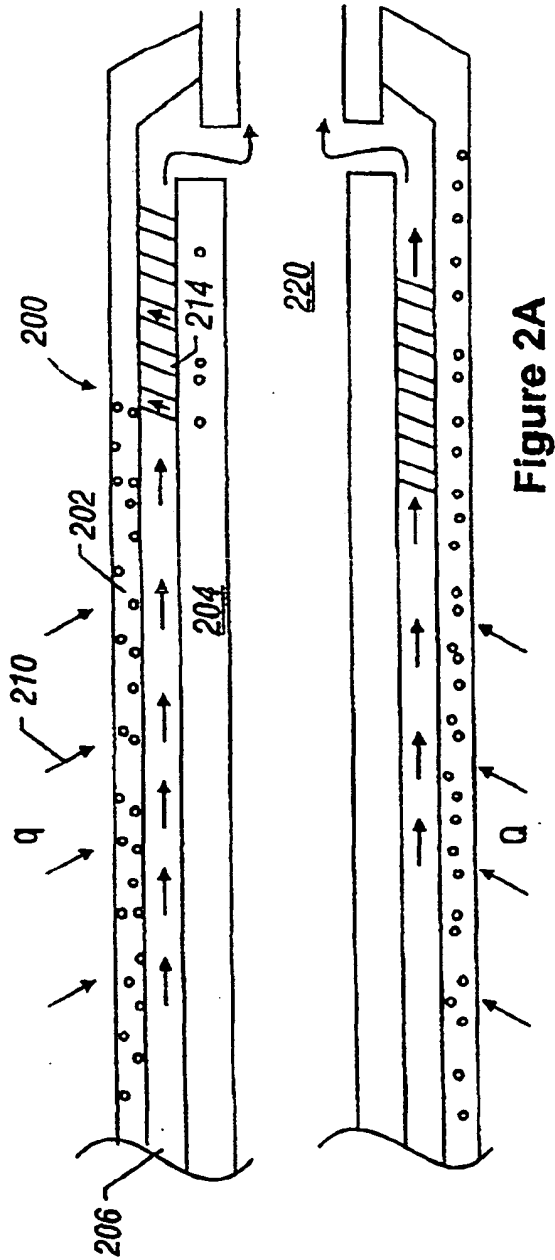


Figure 2A

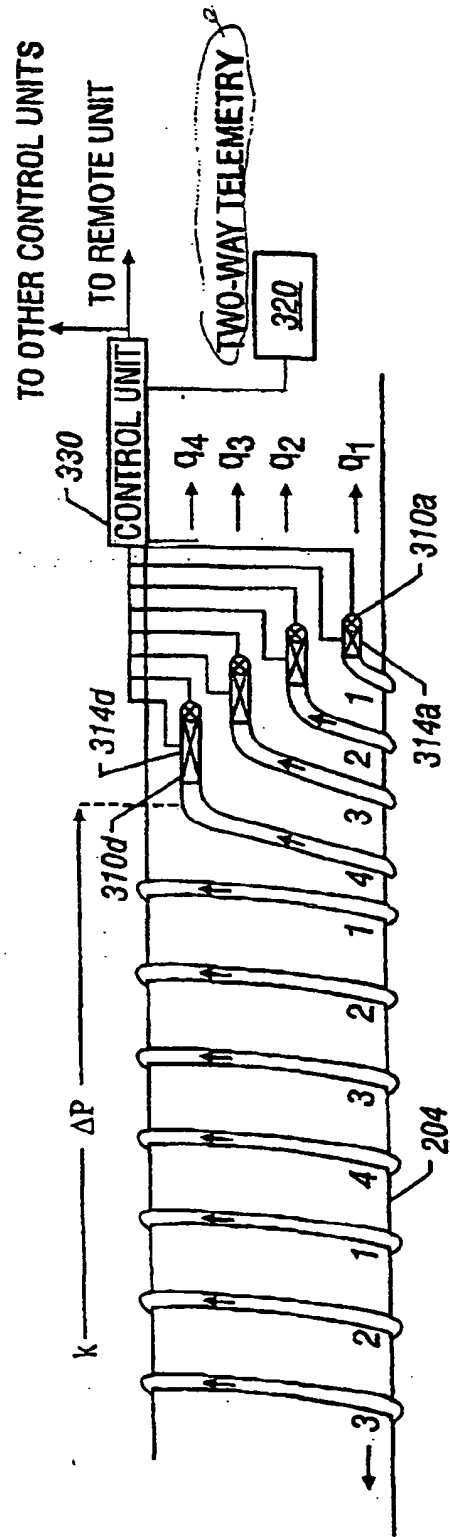


Figure 3

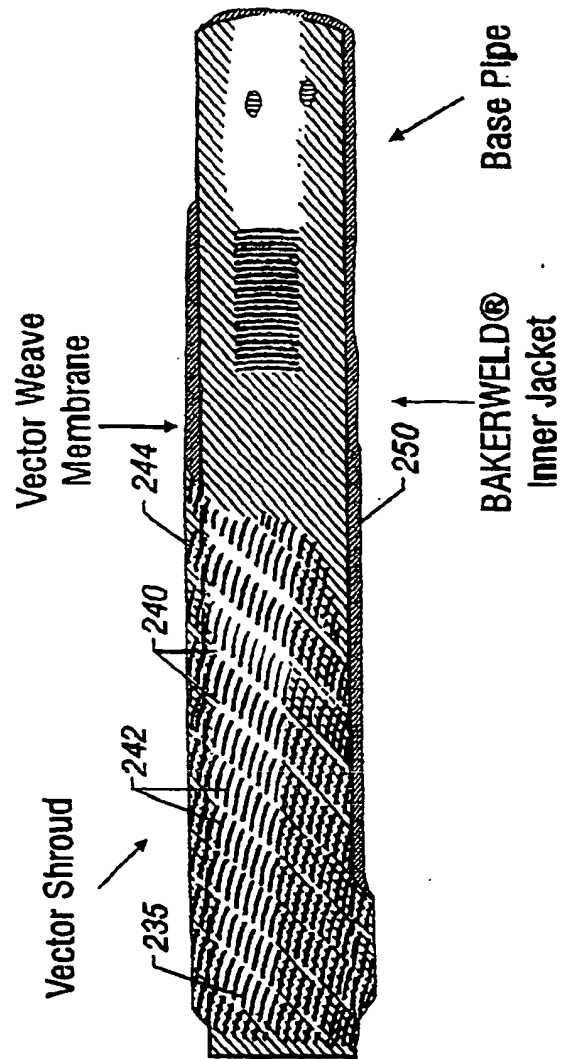


Figure 2B

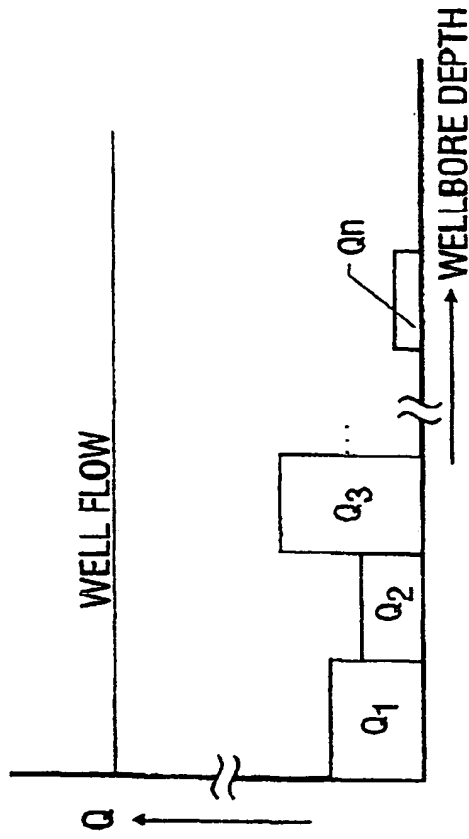


Figure 4

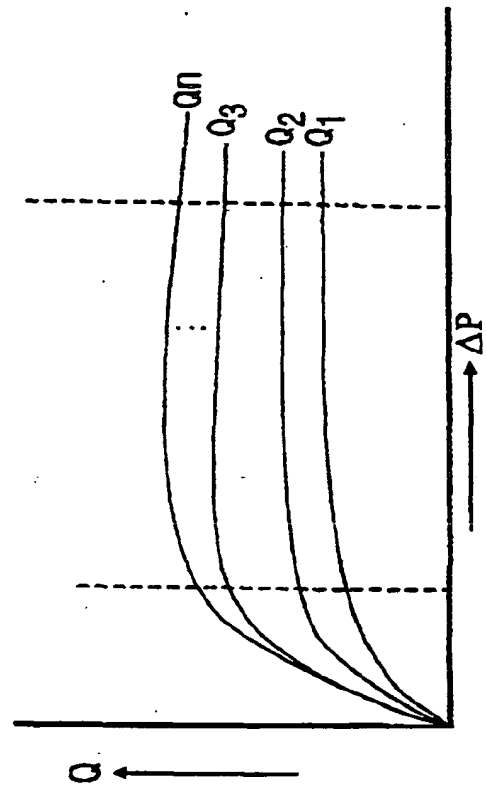


Figure 5

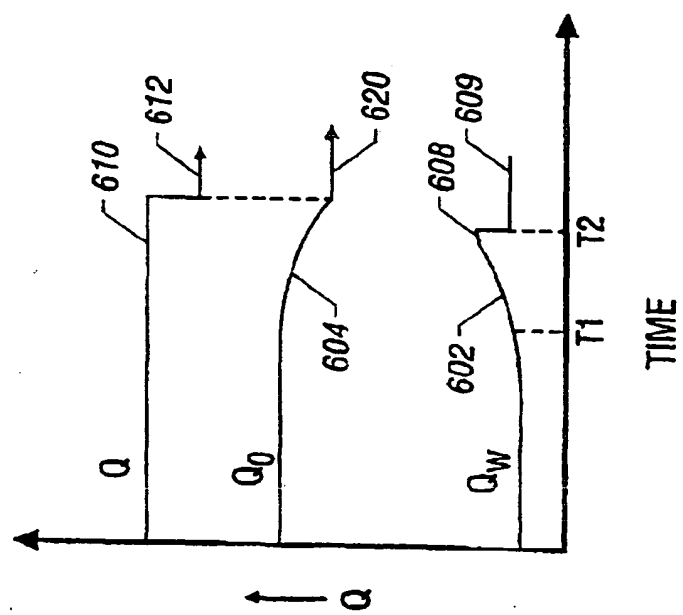
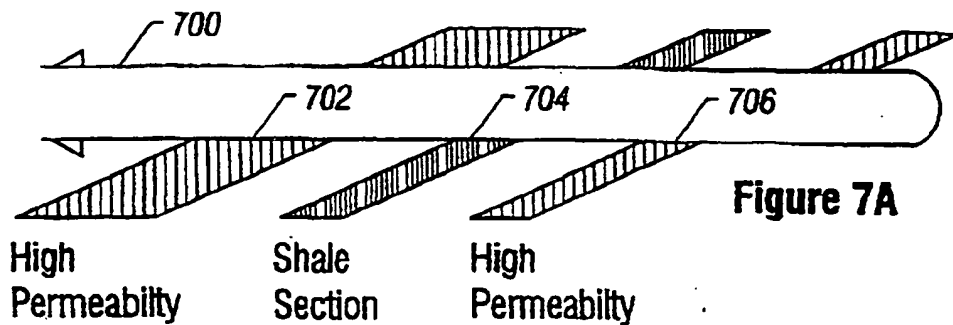
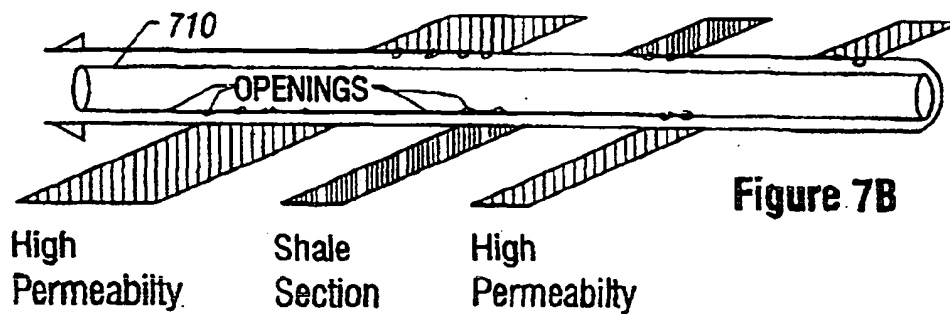


Figure 6

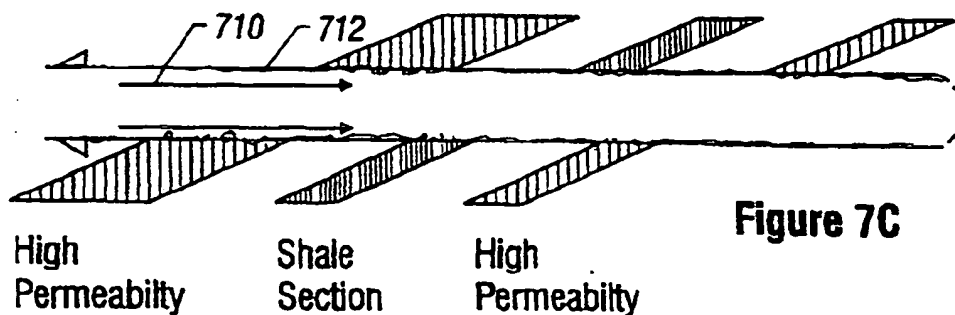
Horizontal Well with Permeability Contrasts and Shale



The well has been drilled, logged and geophysical map has been created



Reservoir Inflow Control Device Is Run In Place



Reservoir Inflow Control Device Is Installed
And Production Liner Can Be Run

FLOW CONTROL APPARATUS AND METHOD

1 **BACKGROUND OF THE INVENTION**

2

3 1. **Field of the Invention**

4

5 This invention relates generally to methods of producing hydrocarbons
6 from wellbores formed in subsurface formations and more particularly to
7 apparatus and methods for regulating and/or equalizing production from
8 different zones of a wellbore to optimize the production from the associated
9 reservoirs or pay zones.

10

11 2. **Background of the Art**

12

13 To produce hydrocarbons from earth formations, wellbores are drilled
14 into reservoirs or pay zones. Such wellbores are completed and perforated
15 at one or more zones to recover hydrocarbons from the reservoirs.
16 Horizontal wellbores are now frequently formed into a pay zone to increase
17 production and to obtain on the aggregate higher quantities of the
18 hydrocarbons from such reservoirs.

19

20 Sand screens of various designs and slotted liners are commonly
21 placed between the formation and a tubing (production tubing) in the

1 wellbore, which transports formation fluid to the surface to prevent entry of
2 sand and other solid particulates into the tubing. Screens of different sizes
3 and configuration are commonly used as sand control devices. The prior art
4 screens typically erode substantially over time. The present invention
5 provides a screen which is less susceptible to erosion compared to prior art
6 screens.

7
8 Excessive fluid flow rates from any production zone can cause,
9 among other things, excessive pressure drop between the formation and the
10 wellbore casing, relatively quick erosion of inflow devices, water or gas
11 coning, caving, etc. Therefore, to avoid such problems, fluid flow from each
12 production zone is controlled or regulated. Several flow control devices have
13 been utilized for regulating or controlling production of formation fluids. One
14 recent device passes the formation fluid through a spiral around a tubular to
15 reduce the pressure drop before the fluid is allowed to enter the tubing. The
16 spiral provides a tortuous path, which can be plugged at one or more places
17 to adjust the fluid flow from the formation to the tubing. This device,
18 although effective, must be set at the surface prior to its installation. United
19 States Patent Application Serial No. 08/673,483 to Coon, filed on July 1,
20 1996, and assigned to the assignee of this application, discloses an
21 electrically operable sliding sleeve for controlling fluid flow through a

1 tortuous path. This sliding sleeve may be operated from the surface. U.S.
2 Application No. 08/673,483 is incorporated herein by reference. The
3 present invention provides a flow control device that can be opened, closed
4 or set at any intermediate flow rate from the surface. It also includes
5 multiple fluid paths, each of which may be independently controlled to
6 control the formation-fluid flow into the tubing.

7
8 In vertical wellbores, several zones are produced simultaneously. In
9 horizontal wellbores, the wellbore may be perforated at several zones, but
10 is typically produced from one zone at a time. This is because the prior art
11 methods are not designed to equalize flow from the reservoir throughout the
12 entire wellbore. Further, the prior art methods attempt to control pressure
13 drops and not the fluid flows from each of the zones simultaneously.

14
15 The present invention provides methods for equalizing fluid flow from
16 multiple producing zones in a horizontal wellbore. Each production zone may
17 be independently controlled from the surface or downhole. This invention
18 also provides an alternative system wherein fluid flow from various zones is
19 set at the surface based on reservoir modeling and field simulations.

20

1 **SUMMARY OF THE INVENTION**

2

3 The present invention provides a fluid flow control device for
4 controlling the formation-fluid flow rate through a production string. The
5 device includes a generally tubular body for placement into the wellbore.
6 The tubular body is lined with a sand screen and an outer shroud. The
7 shroud reduces the amount of fluid that directly impacts the outer surface
8 of the screen, thereby reducing the screen erosion and increasing the screen
9 life. The fluid from the screen flows into one or more tortuous paths. Each
10 tortuous path has an associated flow control device, which can be activated
11 to independently open or close each tortuous path. Alternatively, flow from
12 each path may be regulated to a desired rate.

13

14 Each flow control device further may include a control unit for
15 controlling the output of the flow control device. The control unit may
16 communicate with a surface control unit, which is preferably a computer-
17 based system. The control unit performs two-way data and signal
18 communication with the surface unit. The control unit can be programmed
19 to control its associated device based on command signals from the surface
20 unit or based on programs stored in the control unit. The communication
21 may be via any suitable data communication link including a wireline,

1 acoustic and electromagnetic telemetry system. Each flow control device
2 may be independently controlled without interrupting the fluid flow through
3 the production string. The flow control devices may communicate with each
4 other and control the fluid flow based on instructions programmed in their
5 respective control units and/or based on command signals provided from the
6 surface control unit.

7
8 In a preferred method, a plurality of spaced apart flow control device
9 are deployed along the length of the horizontal wellbore. In one method of
10 the invention, it is preferred to draw fluids from various zones in a manner
11 that will deplete the reservoir uniformly along the entire length of the
12 wellbore. To achieve uniform depletion, each flow control device is initially
13 set at a rate determined from initial reservoir simulations or models. The
14 depletion rate, water, oil and gas content, pressure, temperature and other
15 desired parameters are determined over a time period. This data is utilized
16 to update the initial reservoir model, which in turn is utilized to adjust the
17 flow rate from one or more zones so as to equalize the flow rate from the
18 reservoir.

19

20 In an alternative method, production zones are defined and flow
21 setting for each zone is fixed at the surface prior to installation of the flow

1 control devices. Such a system is relatively inexpensive but would only
2 partially equalize the production from the reservoir as it would be based on
3 *a priori* reservoir knowledge.

4

5 The present invention provides a method of producing hydrocarbons
6 from a reservoir having a deviated/substantially horizontal wellbore formed
7 therein, said method, comprising: (a) placing a plurality of flow control
8 devices in the wellbore, each flow control device set to produce formation
9 fluid at an initial rate associated with each such flow control device; (b)
10 determining at least one characteristic of the fluid produced through the
11 wellbore; and (c) adjusting the flow rate through said flow control devices
12 so as to equalize depletion of hydrocarbons from the reservoir over a time
13 period.

14

15 Examples of the more important features of the invention have been
16 summarized rather broadly in order that the detailed description thereof that
17 follows may be better understood, and in order that the contributions to the
18 art may be appreciated. There are, of course, additional features of the
19 invention that will be described hereinafter and which will form the subject
20 of the claims appended hereto.

21

1 **BRIEF DESCRIPTION OF THE DRAWINGS**

2

3 For detailed understanding of the present invention, reference should

4 be made to the following detailed description of the preferred embodiment,

5 taken in conjunction with the accompanying drawings, in which like elements

6 have been given like numerals, and wherein:

7

8 **FIG. 1** shows a horizontal wellbore having a plurality of spaced apart

9 flow control devices for producing hydrocarbons from a reservoir according

10 to one method of the present invention.

11

12 **FIG. 2A** shows a partial schematic view of a flow control device for

13 use in the system shown in **FIG. 1**.

14

15 **FIG. 2B** shows a partial cut off view of a sand control section for use

16 with the flow control device of **FIG. 2A**.

17

18 **FIG. 3** shows control devices and certain sensors for use with the flow

19 control device of **FIG 2A**.

20

21 **FIG. 4** shows a hypothetical graph showing the flow rate from various

1 zones of a horizontal wellbore according to one method of the present
2 invention.

3

4 FIG. 5 shows a relationship between the pressure differential and the
5 flow rate associated with various production zones of a wellbore.

6

7 FIG. 6 shows a scenario relating to the effect of adjusting the flow
8 rate from a production zone on production of hydrocarbons and water from
9 such zone.

10

11 FIG. 7 shows an alternative method of equalizing production from a
12 reservoir by a horizontal wellbore to the method of system of FIG. 1

13

14 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

15

16 FIG. 1 is a schematic illustrating a system 10 for producing
17 hydrocarbons from a wellbore according to one method of the present
18 invention. FIG. 1 shows a wellbore 14 having an upper casing 12 formed in
19 an earth formation 11 according to any known method. A plurality of fluid
20 flow devices or fluid flow devices 20a-n are placed spaced apart in the
21 horizontal segment 14a of the wellbore 14. For the purposes of this

1 disclosure, a flow control device is generally designated by numeral 20. The
2 construction and operation of a novel flow control device for use as the flow
3 control devices 20 are described below in reference to FIGS 2A-8. However,
4 for the purpose of this invention, any suitable flow control device may also
5 be used. The spacings between the flow control devices 20 are determined
6 based on the characteristics of the reservoir 11, as described in more detail
7 later.

8
9 Each flow control device 20a-n includes a flow valve and a control
10 unit. The devices 20a-n are respectively shown to contain flow regulation
11 devices such as valves, valves 24a-n and control units 26a-n. For the
12 purposes of this invention, a flow control device is generally designated by
13 numeral 24 and a control unit is generally designated by numeral 26. Also,
14 for the purpose of this invention, flow control valves 24 shall mean to
15 include any device that is utilized to control the flow of fluid from the
16 reservoir 11 into the wellbore 14 and control units 26 shall mean to include
17 any circuit or device that controls the flow valves 24.

18 When the wellbore is in production phase, fluid 40 flows from the
19 formation 11 into channels 22a - 22n at each flow control device, as shown
20 by the arrow 22a'-22n'. The flow rate through any flow control devices 20
21 will depend upon the setting of its associated flow control valve 24. For the

1 purpose of illustration, the flow rates associated with the flow control
2 devices 20a-20n are respectively designated by Q_1-Q_n corresponding to
3 production zones Z_1-Z_n of the formation 11.

4 Still referring to FIG. 1, each flow control device 20a-20n or zone Z_1-
5 Z_n may have any number of devices and sensors for determining selected
6 formation and wellbore parameters. Elements 30a-30n respectively
7 represent such devices and sensors corresponding to flow control devices
8 20a-20n or zones Z_1-Z_n . Such devices and sensors are generally designated
9 by numeral 30. Devices and sensors 30 preferably include temperature
10 sensors, pressure sensors, differential pressure sensors for providing the
11 pressure drop between selected locations corresponding to the production
12 zones Z_1-Z_n , flow rate devices, and devices for determining the constituents
13 (oil, gas and water) of the formation fluid 40. Packers 34 may be
14 selectively placed in the wellbore 14 to prevent the passage of the fluids
15 through the annulus 39 between adjacent sections.

16

17 The control units 26a-26n control the operation of their associated
18 flow control valves 24a-24n. Each control unit 26 preferably includes
19 programmable devices, such as microprocessors, memory devices and other
20 circuits for controlling the operation of the flow control devices 20 and for
21 communicating with other sensors and devices 30. The control units 26

1 also may be adapted to receive signals and data from the devices and
2 sensors 30 and to process such information to determine the downhole
3 conditions and parameters of interest. The control units 26 can be
4 programmed to operate their corresponding flow control devices 20 based
5 upon stored programs or commands provided from an external unit. They
6 preferably have a two way communication with a surface control system 50.
7 The surface control system 50 preferably is a computer-based system and
8 is coupled to a display and monitor 52 and other peripherals, generally
9 referred to by numeral 54, which may include a recorder, alarms, satellite
10 communication units, etc.

11

12 Prior to drilling any wellbore, such as the wellbore 12, seismic surveys
13 are made to map the subsurface formations, such as the formation 11. If
14 other wellbores have been drilled in the same field, well data would exist for
15 the field 11. All such information is preferably utilized to simulate the
16 condition of the reservoir 11 surrounding the wellbore 14. The reservoir
17 simulation or model is then utilized to determine the location of each flow
18 control device 20 in the wellbore 14 and the initial flow rates Q_1-Q_n . The
19 flow control devices 20a-20n are preferably set at the surface to produce
20 formation fluids therethrough at such initial flow rates. The flow control
21 devices 20a-20n are then installed at their selected locations in the wellbore

1 14 by any suitable method known in the art.

2

3 The production from each flow control device 20 achieves a certain
4 initial equilibrium. The data from the devices 30a-30n is processed to
5 determine the fluid constituents, pressure drops, and any other desired
6 parameters. Based on the results of the computed parameters, the initial or
7 starting reservoir model is updated. The updated model is then utilized to
8 determine the desired flow rates for each of the zones Z_1 - Z_n that will
9 substantially equalize the production from the reservoir 11. The flow rate
10 through each of the flow control devices 20a-20n is then independently
11 adjusted so as to uniformly deplete the reservoir. For example, if a particular
12 zone starts to produce water at more than a preset value, the flow control
13 device associated with such zone is activated to reduce the production from
14 such zone. The fluid production from any zone producing mostly water may
15 be completely turned off. This method allows manipulating the production
16 from the reservoir so as to retrieve the most amount of hydrocarbons from
17 a given reservoir. Typically, the flow rate from each producing zone
18 decreases over time. The system of the present invention makes it possible
19 to independently and remotely adjust the flow of fluids from each of the
20 producing zones, without shutting down production.

21

1 The control units 26a-26n may communicate with each other and
2 *control the fluid flow through their associated flow control devices to*
3 optimize the production from the wellbore 14. The instructions for
4 controlling the flow may be programmed in downhole memory (not shown)
5 associated with each such control unit or in the surface control unit 50.
6 Thus, the present invention provides a fluid flow control system 10, wherein
7 the flow rate associated with a number of producing zones Z_1 - Z_n may be
8 independently adjusted, without requiring physical intervention, such as a
9 shifting device, or requiring the retrieval of the flow control device or
10 requiring shutting down production.

11
12 The surface control unit 50 may be programmed to display on the
13 display unit 52 any desired information, including the position of each flow
14 control valve 24a-24n, the flow rate from each of the producing zones Z_1 - Z_n ,
15 oil/water content or oil and gas content, pressure and temperature of each
16 of the producing zones Z_1 - Z_n , and pressure drop across each flow control
17 device 20a-20n.

18 Still referring to FIG. 1, as noted above, the system 10 contains
19 various sensors distributed along the wellbore 14, which provide information
20 about the flow rate, oil, water and gas content, pressure and temperature of
21 each zone Z_1 - Z_n . This information enables determination of the effect of

1 each production zone Z_1 - Z_n on the reservoir 11 and provides early warnings
2 about potential problems with the wellbore 14 and the reservoir 11. The
3 information is also utilized to determine when to perform remedial work,
4 which may include cleaning operations and injection operations. The system
5 10 is utilized to determine the location and extent of the injection operations
6 and also to monitor the injection operations. The system 10 can be operated
7 from the surface or made autonomous, wherein the system obtains
8 information about downhole parameters of interest, communicate
9 information between the various devices, and takes the necessary actions
10 based on programmed instructions provided to the downhole control units
11 26a-26n. The system 10 may be designed wherein the downhole control
12 units 16a-16n communicate selected results to the surface, communicate
13 results and data to the surface or operate valves 24a-24n and 30a-30n
14 based on commands received from the surface unit 50.

15

16 FIG. 2A shows a partial schematic view of a flow control device 200
17 for use in the system of FIG. 1. The device 200 has an outer sand control
18 element 202 and an inner cylindrical member 204 together forming a fluid
19 channel 206 therebetween. Formation fluid enters the channel 206 via the
20 sand control element 202. The channel 206 delivers the formation fluid 210
21 to one or more spiral tubings or conduits 214 or tortuous paths, which

1 reduce the pressure drop between the inlet and the outlet of the spiral
2 tubings 214. The fluid 210 leaving the tubings 214 is discharged into the
3 production tubing 220 from where it is transported to the surface.

4

5 FIG. 2B shows a partial cut-off view of a sand control section 235 for
6 use with the flow control device 200 of FIG. 2A. It includes an outer shroud
7 235 which has alternating protruded surfaces 240 and indented or receded
8 surfaces 242. The protruded surfaces 240 have sides 244 cut at an angle
9 providing a vector design. This vector design inhibits the impact effect of
10 the formation fluid on the shroud 235 and the screen 250, which is disposed
11 inside the shroud 235.

12

13 FIG. 3 is a schematic illustration showing a control unit for controlling
14 the flow through the flow control device 200 of FIG. 2. FIG. 3 shows four
15 tubings 214 numbered 1-4 and helically placed around the tubular device
16 204 (FIG. 2A). The tubings 1-4 may be of different sizes. A flow control
17 device at the output of each of the tubings 1-4 controls the fluid flow
18 through its associated tubing. In the example of FIG. 3, valves 310a-310d
19 respectively control flow through tubings 1-4. A common flow control
20 device (not shown) may be utilized to control the flow of fluid through the
21 tubings 1-4. Flow meters and other sensors, such as temperature sensors,

1 pressure sensors etc. may be placed at any suitable location in the device
2 200. In FIG. 3, flow measuring devices 314a-314d are shown disposed at
3 the tubing 1-4 outlets. The output from the tubings 1-4 is respectively
4 shown by q_1 - q_4 . A suitably disposed control unit 330 controls the operation
5 of the valves 310a-310d and receives information from the devices 314a-
6 314d. The control unit 330 also processes information from the various
7 suitably disposed devices and sensors 320 that preferably include: resistivity
8 devices, devices to determine the constituents of the formation fluid,
9 temperature sensors, pressure sensors and differential pressure sensors, and
10 communicates such information to other devices, including the surface
11 control unit 50 (FIG. 1) and other control units such as control units 26a-26n
12 (FIG. 1).

13

14 FIGS. 4 and 5 illustrate examples of flow rates from multiple reservoir
15 segments. In FIGS. 4 and 5, the flow rates Q_1 - Q_n correspond to the zones
16 Z_1 - Z_n shown in FIG. 1. The actual flow rates are determined as described
17 above. By manipulating the flow rates Q_1 - Q_n , optimum flow rate profile for
18 the reservoir can be obtained. The total reservoir flow rate Q shown along
19 the vertical axis is the sum of the individual flow rates Q_1 - Q_n . Here the fluid
20 regulating device (such as 310a-310n, FIG 7) utilized to control the fluid
21 discharge from the tortuous path operates at a fluid velocity where the fluid

1 flow from the formation is substantially insensitive to pressure changes in
2 the formation near the flow control device and, thus, acts as a control valve
3 for controlling the fluid discharge from the formation. This is shown by the
4 position between dotted lines in FIG. 5, where Δp is the pressure drop.

5
6 FIG. 6 shows how adjusting the flow rate Q can reduce or eliminate
7 production of unwanted fluids from the reservoir. It shows the potential
8 impact of adjusting the flow rate on the production of constituents of the
9 formation fluid. Q_o denotes the oil flow rate and Q_w denotes the water flow
10 rate from a particular zone. As the formation fluid flow continues over time,
11 the water production Q_w may start to increase at time T_1 and continue to
12 increase as shown by the curved section 602. As the water production
13 increases; the oil production decreases, as shown by the curved sections
14 604. The system of the present invention would adjust the flow rate, i.e.,
15 increase or decrease the production so as to reduce the water production.
16 The example of FIG. 6 shows that decreasing the overall production Q from
17 level 610 to 612 reduces the water production from level 608 to level 609
18 and stabilizes the oil production at level 620. Thus, in the present invention,
19 the overall production from a reservoir is optimized by manipulating the
20 production flows of the various production zones. The above described
21 methods equally apply to production from multi-lateral wellbores.

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FIG. 7A-7C show an alternative method of equalizing production from a horizontal wellbore. FIG. 7A shows a horizontal wellbore with zones 702, 704 and 706 having different or contrasting permeabilities. The desired production from each of the zones is determined according to the reservoir model available for the wellbore 700, as described above. To achieve equalized production from the various zones, a flow control device 710 in the form of a relatively thin liner is set in the wellbore 700. The liner 710 has openings corresponding to the areas that are selected to be produced in proportion to the desired flow rates from such areas. The openings are preferably set or made at the surface prior to installation of the liner 710 in the wellbore. To install the liner 710, an expander device (not shown) is pulled through the inside of the liner 710 to create contact between the formation 700 and the liner 710. A sand control liner 712 is then run in the wellbore to ensure borehole stability when the wellbore is brought to production. Thus, in one aspect, this method comprises: drilling and logging a wellbore; determining producing and isolated intervals of the wellbore; installing reservoir inflow control system; installing a production liner in the wellbore; installing a production tubing in the wellbore; and producing formation fluids.

1 While the foregoing disclosure is directed to the preferred
2 embodiments of the invention, various modifications will be apparent to
3 those skilled in the art. It is intended that all variations within the scope and
4 spirit of the appended claims be embraced by the foregoing disclosure.
5

1 **Claims:**

2

3 1. A system for producing formation fluid through a production tubing in a
4 wellbore formed in a formation comprising:

5 (a) at least one fluid flow device disposed in the wellbore, each
6 said at least one fluid flow device having a flow line reducing
7 pressure between an inlet receiving such fluid and an outlet
8 discharging said fluid into the production tubing;

9 (b) A flow regulation device controlling the fluid discharge from
10 each said flow line; and

11 (c) A control unit for controlling the operation of the flow regulation
12 device to control the fluid flow into the production tubing.

13

14 2. The system of claim 1 wherein the at least one fluid flow device
15 includes a plurality of spaced apart fluid flow devices arranged serially in the
16 wellbore.

17

18 3. The system of claim 2 wherein the control units control the flow of
19 formation fluid through each fluid flow device.

20

21 4. The system of claim 3 wherein the control units control the flow upon
receiving a command sign from a remote location.

- 1 5. The system of any preceding claim wherein the flow line is a tubing helically
2 arranged around a tubular member, providing a tortuous path for the flow of
3 formation fluid therethrough.
4
5
- 6 6. The system of any preceding claim wherein the flow line indicates a plurality of
7 tortuous flow paths and the control device controls the flow of the formation
8 fluid through said tortuous paths.
9
10
- 11 7. The system of any preceding claim wherein each control unit operates
12 independently to substantially uniformly deplete the reservoir.
13
- 14 8. The system of any preceding claim further comprising a sensor in the well bore
15 providing measurements for a downhole production parameter.
16
- 17 9. The system of claim 8 wherein the control unit operates the flow
18 regulation device as a function of the downhole production parameter.
19
- 20 10. The system of claim 9 wherein the downhole production parameter is
21 one of (a) temperature, (b) pressure, (c) flow rate, and (d) resistivity.

- 1 11. A sand control device for use in a wellbore comprising:
- 2 (a) a shroud having plurality of alternating protruded surfaces and
- 3 reeded surfaces with the protruded surfaces having irregular
- 4 surface adapted to reduce the impact of the formation fluid on
- 5 the shroud; and
- 6 (b) a screen disposed in the shroud for preventing the flow of
- 7 certain particulates from passing the screen.
- 8
- 9 12. A method of equalizing production from a wellbore having a plurality
- 10 of production zones comprising:
- 11 (a) Conveying an expandable liner into the wellbore, said
- 12 expandable liner having flow paths adjacent each production
- 13 zone for allowing the formation fluid to flow from the production
- 14 zones into the wellbore; and
- 15 (b) expanding the liner within the well to place said liner in contact
- 16 with the wellbore walls; and
- 17 (c) placing a sand control device adjacent each flow path in said
- 18 liner.
- 19
- 20 13. A system for producing formation fluid through a production tubing in
- a wellbore formed in a formation substantially as hereinbefore described
- with reference to the accompanying drawings.

14. A sand control device for use in a wellbore substantially as
hereinbefore described with reference to the accompanying drawings.

5 15. A method of equalizing production from a wellbore having a plurality
of production zones substantially as hereinbefore described with
reference to the accompanying drawings.



Application No: GB 9809705.8
Claims searched: 1-10+13

Examiner: Richard Collins
Date of search: 1 October 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:
UK CI (Ed.P): E1F FLE, FLM, FLW, FJF.
Int CI (Ed.6): E21B
Other: None

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2302114 A (Baker Hughes Incorporated) abstract.	-
A	GB 851096 A (Sun Oil Co.) Whole document.	-
A	US 5597042 A (Baker Hughes Incorporated) abstract.	-

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